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Temperature Measurement on Shocked Surfaces

P. Poulsen, D. Baum, P. Fiske, D. Holtkamp

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National
Laboratory

Temperature Measurement on Shocked Surfaces

Peter Poulsen, Dennis Baum, Peter Fiske,
Lawrence Livermore National Laboratory,
and
David Holtkamp,
Los Alamos National Laboratory

Abstract

We have used a two-stage gas gun to address issues relating to the accurate determination of the temperature of a shocked metal surface at a metal / LiF interface. We have investigated the light flash generated by the dynamics at the interface, the light sources at the LiF boundary that can contaminate the emission from the metal surface, and the light emitted from defects in the LiF crystal as it is being shocked. A seven-channel spectrometer with fiber-optic transmission of light from the target was used, and a Hohlraum geometry was used to increase the effective emissivity of the target. The method that yielded the best results is described and is expected to be useful for a wide range of applications.

Temperature measurement

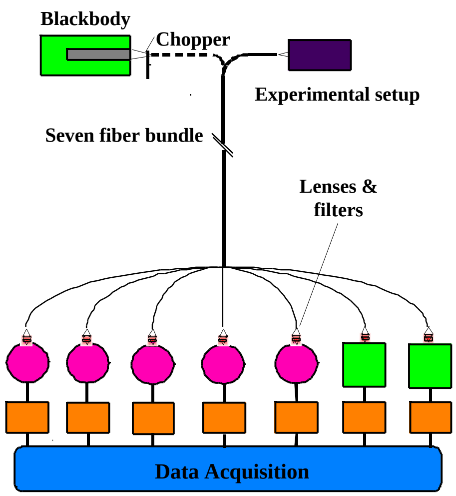
The measurement of temperature is an important check on the constitutive equations for materials that are used in numerical simulations. For example, the ductility of a metal is a function of the temperature, and numerical simulations of shaped charge jet formation depend on the accurate knowledge of the relationships.

It is necessary to eliminate or quantify all additional sources of light when measuring the emitted light from a shocked surface. Light sources are plentiful and include light from the gun environment, light generated at the metal / LiF anvil interface, and light generated due to edges and jets that are subjected to large amounts of shear. In addition, it has been found that the LiF anvil itself can emit light after the passage of the shock.

The muzzle flash from the gun environment can be largely eliminated by using a fiber-optic connection between the target and the diagnostic, arranging the shielding such that only the fibers have access to the shocked surface. We arranged to collaborate with David Holtkamp at LANL who had developed a state-of-the-art multi-channel spectrometer using fiber optics (Fig. 1). The fiber optics were constructed at and supported by Bechtel Nevada (Los Alamos). The experiments were run at the LLNL two-stage gas gun under the leadership of Peter Fiske.

The experiments investigated techniques that would minimize contamination of the emitted light from the shocked metal surface, and at the same time maximize the emitted light. Gaps and microscopic irregularities in the interface between the metal surface and the LiF crystal give rise to a flash of light as it is traversed by the shock. A primary objective of the experiments was to minimize this effect. A second source of light was due to either coating on the crystal, or jetting at the crystal / metal surface junction. This was eliminated by using a geometry where the shock did not reach the crystal edge during the period of interest. A third and important source of light is the crystal itself; emission from the crystal was investigated by using the crystal as both the flyer and the target. We'll describe the series of experiments where these issues were addressed, and show that an experimental configuration was found that appears to be satisfactory.

Having acquired some confidence in the validity of the experimental technique, we are now building a similar spectrometer, which takes advantage of recent developments in fiber-optic technology. This spectrometer will be used initially to measure the temperature of shocked surfaces, and then the temperature of surfaces that have been isentropically compressed. The latter information will provide important information on the constitutive relationship for the compressed materials.



P-22 Pyrometer Configuration

Channel	Spectral range (μm)
1	1.00 – 2.50
2	1.27 – 2.50
3	2.00 – 2.38
4	1.50 – 1.80
5	1.13 – 1.35
6	0.79 – 0.82
7	0.69 – 0.72

Figure 1. A schematic of the multi-channel pyrometer.

LiF light emission

The emission of light by shocked LiF can be a serious problem when the LiF crystal is used as an anvil for a shocked material surface. In the first set of experiments we measured the light generated when two LiF crystals collided. Two experiments were conducted, one with an impact velocity of 0.7 km/sec and another with an impact velocity of 1.8 km/sec. The result is shown in Fig. 2. At a velocity of 0.7 km/sec, little light is generated, especially at early times; at the greater velocity plenty of light is generated. However, in this experiment we exceed the strength of LiF during the acceleration of the LiF projectile, leaving the interpretation of the results uncertain.

Three features in Fig. 2 merit discussion. The first (labeled “X-Ray”) was generated in the photomultiplier detectors by the electromagnetic emission of the second flash x-ray unit used to measure the flyer plate velocity and tilt. The second feature (“Impact Gas Flash”) is most likely the emission of the shocked residual gas remaining in the imperfect vacuum of the target chamber. An important feature is created about two microseconds after impact and is a marked increase in the emission from the LiF. At this point we are uncertain about the origin of this emission. Mechanisms suggested include the interaction between the shock wave compression and defects in the crystal, and by tension and cracking associated with the release waves from the crystal edges. It is important for the measurement of the metal surface temperature to be able to control the magnitude and / or timing of the light emitted from the crystal.

In a later experiment, we used the LiF as an anvil for a shocked copper disc. The geometry largely eliminated edge effects and used a Hohlraum to increase the effective emissivity of the copper surface. The geometry is illustrated in Fig. 3. In this experiment, the Cu disk was impacted by a Cu flyer at a velocity of 1.8 km/sec. The LiF was coated with 5000 Angstrom of copper at the interface with the metal target. The emissivity of the plated copper was extremely low, limiting the emission from the copper surface. It was apparent, however, that the LiF did emit with increasing magnitude after the shock entered the LiF (Fig. 4). It appears to be possible to measure the metal surface radiation without the contribution from the LiF crystal at a time of 0.5 to 0.7 microsecond after shock breakout, but after that the emission from the crystal produces an optical contamination.

The conclusion from these experiments is that the LiF crystal does not emit significantly at low pressures (50 kbar or less), but can and does emit at higher pressures. The emission is observed to be low at early times after the shock breakout, and this allows the measurement to be taken even at high pressure. It is important to have sufficient time resolution in the diagnostic and to minimize the interface flash so the temperature measurement can be accomplished before the emission from the LiF crystal is significant. Since the emission from the metal surface is constant as long as the metal/LiF interface is held at constant pressure, it is possible to measure the equilibrium temperature of the partially released metal at the interface.

Metal — crystal interface emission

Examination of the data in Fig. 4 shows that a flash of light was emitted as the shock passed the metal — crystal interface. For this experiment, the LiF crystal was polished and coated with layer of copper. The copper surface was also polished and the two surfaces were held in contact by mechanical means. No glue or other material was introduced between the surfaces to eliminate the microscopic void spaces.

An experiment was performed that was similar to that of Fig. 3, except that this time we used Stycast glue to fill the void between the Cu coating on the LiF crystal and the copper target. This approach appears to have caused problems since the pyrometry signals (not shown) exhibited large and irregular peaks, especially in the visible channels. Our interpretation was that the Stycast glue radiates strongly when shocked and was shining through cracks (or pinholes) in the copper coating on the LiF crystal.

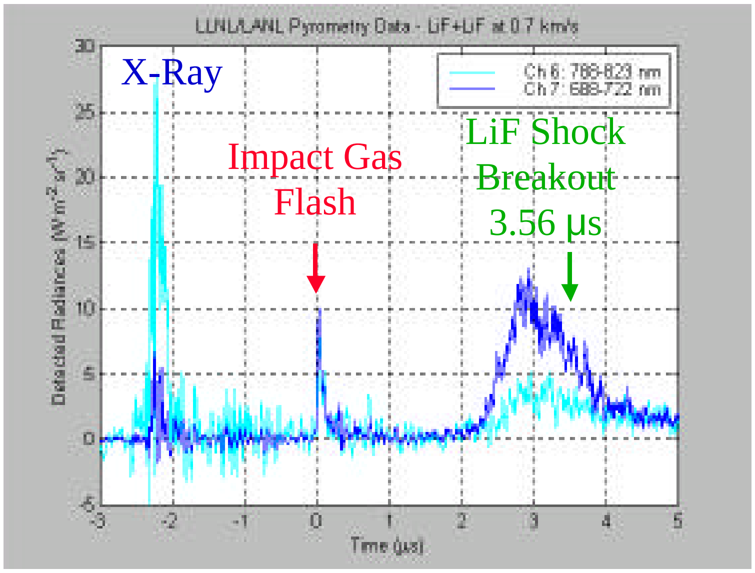


Figure 2. The emission of light from LiF impacted at 0.7 km/s is small.

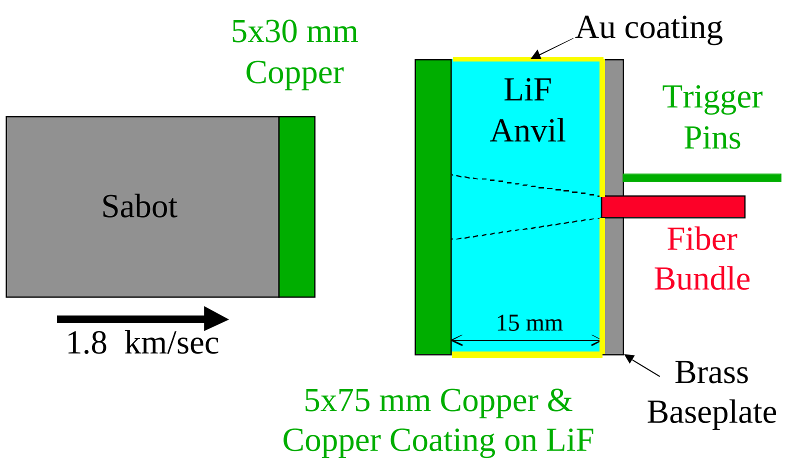


Figure 3. The Cu / LiF Hohlraum configuration.

A subsequent experiment was performed with a greater emissivity molybdenum target to increase the signal from the metal surface. Again, a highly reflecting Hohlraum enclosure was employed to maximize the signals, but the side of the LiF crystal facing the target was not coated with metal. It was left polished but bare, and the space between the target and the LiF crystal was filled by a less than one-micrometer thick layer of UV curable glue. This experiment appeared to work very well, as shown in Fig. 5. The infrared channels are the strongest and exhibit a regular behavior. The best estimate of the surface temperature of the moly is 683 +/– 41 degrees Kelvin. The decrease about one microsecond after shock breakout breakout appears to result from a reduction in the pressure at the Mo/LiF outer radial region of the shocked interface resulting in a decrease in the area of the surface having a high temperature. The subsequent increase in the signal is associated with radiation from the LiF is similar to that observed in the other experiments and is not fully understood at this time.

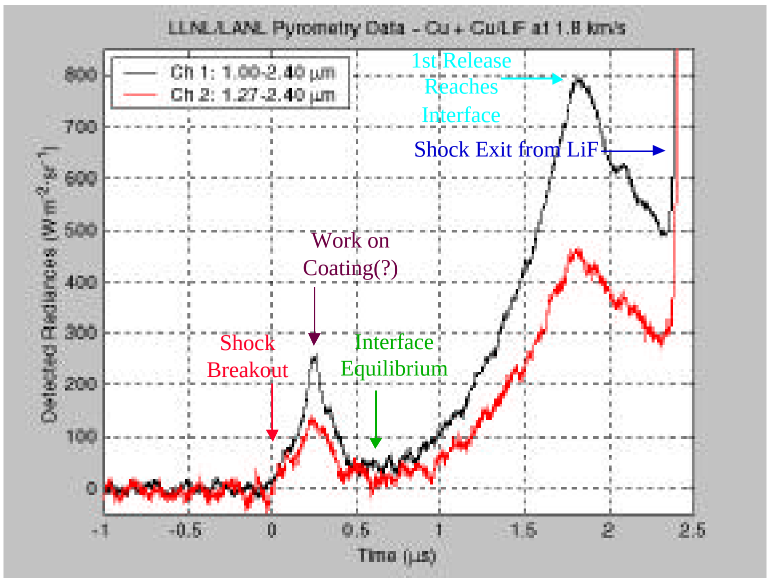


Figure 4. These data illustrate the interface flash and the rise in emission due to the LiF.

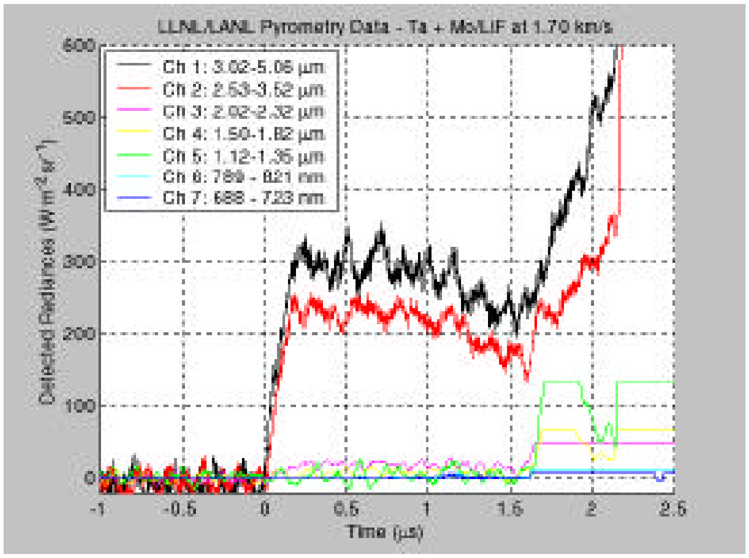


Figure 5. Excellent data was obtained with no metal coating on the LiF and with UV glue at the interface

Plans and objectives of future experiments

It appears that using a thin layer of UV cured adhesive (to eliminate the interface flash problem) and using a Hohlraum configuration to increase the effective emmisivity (hence the emission from the shocked surface) enabled us to obtain a quantitative measurement of the radiation and to calculate the surface temperature. The emission from the LiF crystal has not been eliminated, but the minimization of the flash combined with fast diagnostics enables us to obtain a measurement before the contamination from the crystal radiation is significant. There will be cases involving large shock strengths where it may not be possible to avoid the crystal radiation. In those cases it may be possible to estimate the contribution and subtract it from the signal.

One of the difficulties in using fiber optics to transmit the radiation from the target to the detector is that infrared capable fibers are difficult to work with (being extremely brittle) and have significant transmission losses. Recent work at universities and in industry has improved this situation. In particular, hollow core fibers appear to perform well and are sufficiently rugged for the present application.

Since the series of experiment described above showed that it is possible to obtain an accurate measurement of the radiation from a shocked surface, we have decided to build a device similar to that developed by Holtkamp (and collaborators), taking advantage of recent improvements in fiber technology. This instrument will fist be employed to measure the temperature of shocked surfaces in experiments similar to those described above. It will then be used to measure the internal energy generated during an isentropic radial compression. This data will be valuable in distinguishing between various choices for the constitutive relations for a given metal.

Acknowledgments

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